

**THE USE OF FIBER OPTIC ILLUMINATION IN PERIODONTAL
THERAPY**

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THESIS**

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By
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DEDICATION

I dedicate this thesis to the light of my world, my loving wife Joanne, whose steadfast love, patience, sacrifice and unwavering support has sustained me through these past three years of residency. To my son, Andrew; I count it a blessing to be your father and have delighted in your presence since your birth. To my daughter, the hope of your arrival these past few months has renewed my strength. To my parents, Virgil and Dorothy, you have always supported me along a long and winding path. To my in-laws, Bill and Dorcas, you have helped our family immeasurably and asked nothing in return. To all I am forever grateful.

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Total calculus removal is still the “gold standard” in periodontal therapy. However, the ability to remove all of the calculus from root surfaces is extremely difficult. This is especially true in deep pockets. Surgical access improves our ability to remove more calculus than that removed during a closed procedure, but numerous studies have reported residual calculus despite the use of a surgical approach. Although these studies point out the merits of surgical access, interpretation of the data from such studies is difficult since precise methodologies were not used to quantify residual calculus. Numerous articles have reported on the inaccuracies of commonly used stains and ocular grid systems to quantify residual root deposits. Additionally, no studies have decisively examined the effect of the use of optimum lighting, as that afforded by fiber optic illumination, to improve visualization of calculus at the time of surgery.

Therefore, the first specific aim of this study was to evaluate the effect of fiber optic illumination on the ability to remove calculus when employing a surgical approach. The second specific aim of this study was to determine if illumination in this manner results in difference

between single- and multi-rooted teeth. The third specific aim of this study was to develop a new methodology of quantifying residual calculus on root surfaces. This was accomplished using digital images of scanning electron microscope (SEM) photographs.

The patients in this study were selected from a group of patients presenting for periodontal and/or prosthodontic therapy at Mackown Dental Clinic, Wilford Hall Medical Center, Lackland AFB, Texas. Forty-five teeth from 18 patients were selected for treatment and analysis. The selected teeth exhibited a site which probed at least 5 mm and were scheduled for extraction as part of a comprehensive periodontal/prosthodontic treatment plan. Prior to extraction, 20 teeth were randomly selected to serve as control teeth. Of this group, ten were multi-rooted teeth and ten were single-rooted teeth. Control teeth were scaled and root planed under ordinary dental unit lighting during an open flap procedure. A second set of twenty teeth was randomly selected as test teeth. Similar to the controls, ten were multi-rooted teeth and ten were single-rooted teeth. Test teeth were scaled and root planed using fiber optic illumination during an open flap procedure. The remaining five teeth were randomly selected and served as untreated controls to verify the presence and quantity calculus. None of the study teeth received any periodontal therapy for at least 6 months prior to the clinical phase of the study.

At the surgical appointment, facial and lingual mucoperiosteal flaps were reflected to provide access to the roots of the teeth. The operators were blinded as to the nature of the study and were instructed to use any hand, rotary, and/or ultra-sonic instruments to instrument root surfaces. Root surface debridement continued until the roots were clinically determined to be free of plaque and calculus. No time constraints were imposed. The teeth were then atraumatically extracted, brushed and rinsed in sterile water to remove soft tissues and loose debris. To facilitate blinded evaluation, extracted teeth were individually stored in numbered bottles of

sterile water until laboratory examination. Untreated control teeth were stored in the same manner as the test and treated control teeth.

At the time of laboratory examination, the stored teeth were removed from the bottles and rinsed with sterile water. Desiccation of the teeth was accomplished using a series of graded alcohols and hexamethydisilizane. The desiccated teeth were mounted on scanning electron microscope (SEM) platforms, sputter-coated with gold-palladium, and subsequently viewed and photographed with an Amray 1200® scanning electron microscope. Multiple photographs, from the gingival margin to the attachment apparatus, were taken of all root surfaces available for scaling and root planing during surgery. The SEM photographs were transformed into digital images and captured on a computer with an Olympus Image Analysis System®. These images were then analyzed with the Image Pro Plus Program®. This analysis allowed for the quantification of both the total debridable root surface area and the total residual calculus area of the roots in standardized pixel units.

The data revealed that the use of fiber optic illumination allowed for significantly more calculus to be removed from surgically exposed root surfaces than that removed under ordinary dental unit lighting ($p = .044$). The benefits of fiber optic illumination were similar for single- and multi-rooted teeth and the difference was not significant ($p = .766$). Additionally, the use of SEM photographs and the digital analysis of such photographs was shown to be a highly accurate method of quantifying residual calculus.

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I. Introduction and Literature Review

1. Calculus Removal as Therapy

The original work by Loe *et al.* (1965) established in humans that plaque, allowed to develop in the absence of any oral hygiene, resulted in gingivitis that was reversible with the resumption of plaque control. Calculus, on the other hand, as noted in a review on the subject by Schroeder (1969), acts as harbor of plaque to extend its influence and contribute to the chronicity of periodontal inflammation and disease. Baumhammers and Rohrbaugh (1970) later expounded on the pathogenic contributions of calculus and noted that its permeable surfaces can act as a reservoir for plaque and irritating materials, thereby extending the extension and progression of inflammation. Ainamo (1970) further substantiated the pathogenic effect of calculus on the periodontium in a study of 154 young adults and noted a high and positive relationship between gingivitis and calculus.

Removing of calculus and its adherent plaque is generally accepted as an integral part of comprehensive periodontal treatment. Although time consuming, the mechanical therapy of scaling and root planing remains as the primary methodology to remove such accretions. The therapeutic benefits of this modality of therapy are well supported in the literature. Suomi *et al.* (1971), in a group of adults studied over three years, reported a greater than 3-fold reduction in attachment loss in those patients receiving frequent mechanical debridement (3-4 times per year)

over those receiving only routine prophylaxis. Tagge *et al.* (1975) examined the response of 22 patients to either personal oral hygiene alone or oral hygiene plus root planing. Oral hygiene alone exhibited slight probing depth reductions related to recession and improvement in gingivitis scores. However, scaling and root planing (SC/RP) plus oral hygiene resulted in markedly greater improvements in these parameters and affected a significant gain in clinical attachment. Chawla *et al.* (1975), in the examination of 1600 patients over a 2-year period, specifically concluded that the removal of calculus was directly correlated with the improvement in periodontal health. Hill *et al.* (1981) and Pihlstrom *et al.* (1981 & 1984), additionally reported on the clinical benefits of root debridement over several years and noted greater improvement in clinical indices with effective calculus removal. Hill *et al.* (1981) studied 90 subjects over two years and concluded that scaling with effective debris removal produced the better maintenance of pocket depth reduction than any tested surgical treatments. Pihlstrom *et al.* (1984) studied 17 subjects over 6.5 years and reported pocket depth changes of ≤ 1.54 mm and attachment losses of $\leq .54$ mm with SC/RP. These results exceeded those exhibited by teeth subjected to a modified Widman approach. The overall conclusion of the previous studies indicates that periodontal indices can be significantly improved and maintained if calculus and plaque are effectively removed following root instrumentation.

Despite clinical improvements following SC/RP, studies evaluating efficacy of plaque and calculus removal have shown that complete removal of these substances is often difficult, if not impossible, to attain. For instance, Eschler *et al.* (1991) used a variety of hand and ultrasonic instruments on 90 periodontally-involved and reported that the mean percentages of debrided root surfaces that harbored residual material ranged from 4.3% to 84.1%. Also, Eaton *et al.*

(1985) instrumented 33 teeth, with and without surgical access, and reported that in no instance was any root with stainable deposits.

From a critical analysis of these earlier studies on scaling and root planing, two conclusions can be drawn. First, if calculus and plaque can be removed from the root surfaces, an improvement in periodontal health can be expected. Secondly, therapists are not always able to completely remove these deposits from root surfaces. Therefore, some residual calculus can be tolerated by the periodontal tissues and yet allow them to remain in relative health. The amount of calculus and its adherent plaque that is biologically acceptable or tolerated is currently unknown, and because of this, total debris removal is still considered the "gold standard" of periodontal therapy.

2. Difficulties in Calculus Removal

Removal of calculus from the root surface is complicated by several factors. One such factor is the tenacious adherence of calculus to the root surface and the variety of mechanisms by which calculus adheres. Canis *et al.* (1979) studied and reported on the mechanisms of attachment which include cuticular attachment, mechanical interlocking, and the direct attachment into surface irregularities. Direct attachment can be such that the cementum and calculus appear morphologically similar to the extent that several investigators have used the term "calculo-cementum". Other factors contributing to difficulty in calculus removal are the inherent problems of access due to root anatomy, deep probing depths, poor visualization due to bleeding, inadequate illumination, and other associated problems.

The evidence of the periodontal therapist's lack of ability to thoroughly remove tenacious accretions from the root surfaces is evident in many studies. Sherman *et al.* (1990) scaled and root planed 476 teeth and found that 57% of all treated surfaces thought to be clinically free of deposits had residual calculus. Kepic *et al.* (1990) instrumented 31 teeth with either an open or closed approach. After viewing the treated teeth with both light microscopy and SEM, they concluded that complete calculus removal from a periodontally diseased root surface was rare. These studies suggest that the "gold standard" as described earlier may be very unrealistic.

As stated, another factor working against the effective removal of calculus is the physical depth of the calculus within the pocket. Richardson *et al* (1990) studied 260 intrabony defects ranging from 2 to 14 mm and reported a positive correlation ($r = 0.83$) between increasing depth of intrabony defects and the distance of the most apical calculus from the defect base. They also found that the apical border of the calculus varied positively relative to the depth of the defect. As the calculus progressed apically, so did the attachment with the concomitant increase in pocket depth. Numerous investigations have related that as pocket depth increases, the efficacy of calculus removal decreases. Rabbani *et al.* (1981) studied the efficiency of calculus removal and reported disappointing results. They noted that the percent of residual calculus and pocket depth were positively correlated and concluded that pockets exceeding 5 mm were the most difficult to instrument. Staumbaugh *et al.* (1981) found the average curette was only effective to a pocket depth of only 3.73 mm and that the average limit for any hand instrumentation was 6.21 mm. Therefore, in deeper pockets it is questionable whether instruments can reach the calculus let alone be effective in removing it. It seems that as the pocket deepens and the calculus progresses apically, the hope of total calculus lessens.

An inherent and unavoidable factor complicating the removal of calculus is root anatomy. Numerous investigators have discussed the anatomic challenges to effective root instrumentation and the inadequacies of removing deposits from teeth with multiple roots, furcation invasions, close root proximity, enamel projections, and concavities. Bowers *et al.* (1979) reported that the majority of furcation entrances ($58\% < 0.75$ mm) were smaller than the width of the commonly used curette (0.75-1.10 mm). Gher *et al.* (1981) sectioned extracted human teeth and described root concavities, furcation morphology, and furcation entrances and related them to their clinical significance in the pathogenesis and treatment of periodontal disease. Everett *et al.* (1958) noted that intermediate bifurcation ridges, structures which may complicate effective debridement of the furcation, were present on 73% of mandibular first molars. Withers *et al.* (1981) examined 2,099 maxillary incisors and found palato-gingival grooves in 8.5% of the patients. These grooves occurred most frequently on maxillary laterals (4.4%) and presented problems with localized periodontal disease due to difficulties in adequate debridement. Fleischer *et al.* (1989) and Wylam *et al.* (1986) specifically addressed furcation debridement and described the difficulties in treating multi-rooted teeth. Fleischer *et al.* (1989) debrided 50 molars with and without surgical access and noted that when furcation aspects alone were assessed for debridement efficacy during therapy, even experienced operators obtained a calculus-free surface only 68% of the time. Wylam *et al.* (1993) found that multi-rooted teeth, after open or closed instrumentation, had residual calculus on 33% and 54% of the root surfaces respectively. With respect to furcations alone, Wylam *et al.* (1993) reported that mean furcal root surface coverage of plaque and calculus was 93.2% in teeth treated with a closed procedure compared to 91.1% in

teeth treated with an open flap approach. There was no significant difference between either group relative to deposits remaining in the furcal region.

It appears from these articles and studies, therefore, that the configurations and anomalies of the teeth and their roots can negatively impact the effectiveness of root planing and scaling. Although complete calculus removal following scaling and root planing may be an unrealistic goal, manipulation of other variables involved in root instrumentation may get us closer to the gold standard. One such variable is the type of instrumentation used.

3. Modalities to Improve Efficacy

The standard instrument in root debridement has been and continues to be the curette. However, as noted before in deeper pockets and narrow furcations, the efficacy of the curette is greatly diminished. The arrival of ultrasonics to instrument the root surfaces initially offered great promise. They have since been studied for their effectiveness in removing calculus from furcations and they have exhibited limited improvement in efficacy. Thornton and Garnick (1982) compared closed hand instrumentation to ultrasonic instrumentation for calculus removal and found that 33% of the hand instrumented surfaces and 34% of the surfaces treated with ultrasonics retained calculus. However, they found ultrasonic more effective in posterior furcation areas. Matia *et al.* (1986), in studying the open and closed debridement of 50 teeth with furcation involvement and probing depths ≥ 5 mm, found no differences in efficacy of deposit removal between hand and ultrasonic instrumentation. Hunter (1984) used open flap access and found that areas of residual deposits, expressed as a percentage of root surface, were

less for hand instrumented roots (5.78%) than for roots treated using ultrasonics (6.17%). More recently, Parashis *et al.* (1993) and Yukna *et al.* (1997) have shown that rotary diamonds and diamond-coated ultrasonic inserts have offered some limited positive results in furcation areas. Parashis *et al.* (1993) studied the efficacy of debridement in 30 teeth with furcation involvement and reported that the use of rotary diamonds in furcations resulted in reduced proportions of surfaces with residual calculus, particularly for the furcation flutes. Yukna *et al.* (1997) debrided 80 teeth with a variety of instruments which included diamond-coated ultrasonic inserts. The addition of the diamond coating improved the efficacy of debridement by less than 1% over conventional ultrasonics while removing excessive root structure. In conclusion, residual calculus has remained a problem regardless of the modality of treatment instrumentation used.

4. Open Flap Access for Debridement

In studying the problem of removing calculus, several investigators evaluated the benefits of an open approach to improve access to accretions in deep pockets. This approach, by far, has resulted in the greatest improvements in the efficacy of calculus removal. In general, studies indicate significant improvement in calculus removal with an open approach, but total removal is not assured. Parashis *et al.* (1993) treated 30 first and second molars with open or closed approaches. The percentage of residual calculus on the external non-furcation surfaces was significantly higher after closed than open root planing. Additionally, regardless of the approach, they observed more residual calculus after instrumentation in all pockets ≥ 7 mm but the difference was only significant with the closed approach. Caffesse *et al.* (1985) evaluated

scaling in pockets > 6 mm using open or closed scaling. They found that 50% of the root surfaces had residual calculus after treatment using an closed approach versus 32% using an open approach. Buchanan *et al.* (1986) also studied the effectiveness of scaling and root planing with and without surgical access. They found that calculus-positive teeth (CPT) and calculus positive surfaces (CPS) were significantly lower after scaling and root planing with a flap (37% and 14% for CPT and CPS, respectively) than after scaling and root planing without a flap (62% and 24% for CPT and CPS, respectively). Pihlstrom *et al.* (1983) reported that ≥ 7 mm pockets exhibited significantly greater initial depth reduction in surgical vs. non-surgical instrumentation and speculated that the difference was due primarily to access for more effective calculus removal in the former. Knowles *et al.* (1979) studied 1,974 teeth over 8 years and concluded that root debridement with a modified Widman Flap resulted in significantly greater pocket reduction and attachment gain compared to subgingival curettage alone.

Despite the definite improvements with surgical access, residual calculus apparently remains on the treated root surfaces. One must question the reason for calculus retention even when open flap access affords direct vision and access to the roots and associated anatomical variances. Improvements in access beyond flap expoure may not be possible. However, further improvements in visualization, such as that potentially provided by fiber optic illumination, might improve the effectiveness of calculus removal.

5. Fiber Optic Illumination as an Adjunct to Therapy

Fiber optic illumination has already shown some promise in improving visualization during periodontal procedures, but scant literature has been devoted to fiber optic illumination during treatment. Reinhardt *et al.* (1985, 1991), utilized minimal interdental papilla reflection and reported that $0.57 \pm 0.29\%$ of the treated root surfaces retained residual calculus when using fiber optic illumination vs. $2.42 \pm 0.63\%$ of the root surfaces retaining residual calculus when using direct illumination. Johnson *et al.* (1989), in a similar study, found that teeth debrided with papilla reflection and fiber optic illumination had a significantly lower percentage ($P < 0.01$) of remaining subgingival accretion coverage than those debrided with closed sonic scaling ($1.30 \pm 0.25\%$ vs $6.35 \pm 1.08\%$, respectively). Although definite improvement with fiber optic illumination was noted in such studies, to date, no studies have evaluated the efficacy of calculus removal using a head-mounted fiber optic illumination system during open flap surgery.

6. Calculus Quantification

Over the years, several methods have been developed to detect and quantify the amount of calculus that remains after root debridement. Most of the methods used a staining solution such as methylene blue which, according to Breninger *et al.* (1974), stains residual materials in

addition to calculus (*Plate 1*). The authors questioned the accuracy of previous studies that quantified calculus using such stains.

Another problem relating to accuracy of quantification of residual calculus is the counting method employed. A frequently used method of quantification involves reviewing root surfaces at 10x magnification with a stereomicroscope. In this method, the stereomicroscope is fitted with a grid that divides the field into 100 equal squares. Each square (1/100 of the grid) that contains any stained material is counted as 1 unit. The total number of squares with residual material is divided by the total number of squares for the entire root surface and reported as a percentage. Eschler and Rapley (1991) noted that this method of analysis produced reports of residual calculus that were inflated 2-8 times because the squares were counted as positive regardless of the actual area covered with calculus. Also, since disclosing stains identify materials in addition to calculus, instrumentation may have actually removed more calculus than reported in these studies. One cannot accept the quantities of reported residual calculus using such methods in absolute terms.

The Data Analysis System (ZIDAS) is another system which has been used for calculus quantification in previous studies. This system operates with a digitized analyzer that uses a cursor and cross-hair tracer mechanism to outline residual stained areas. The total area of the sample and the summed total of all of the residual stained areas within the sample are obtained, and the percentage of total stained area for each sample is recorded. Proper quantification of calculus is suspect because of the error associated with manually outlining calculus, its reliance on non-specific stains, and no mechanism to minimize noise and false positives.

Plate 1

Photographs of extracted molar tooth. *Panel A*: Tooth prior to staining for residual deposits. *Panel B*: Same tooth after staining with methylene blue.



Currently, a more advanced image analysis system, the Olympus Image Analysis System®, is available for microscopic quantification. This system uses a camera or microscope that interfaces with a computer. This system, coupled with Image Pro Plus® software, has applications to quantify residual calculus digitally. The computer digitally maps the residual areas and eliminates noise. This significantly improves accuracy relative to the methods used in previous studies. Additionally, images presented for analysis and quantification are highly accurate when enhanced images produced by SEM are utilized. Utilizing these systems in tandem possesses great potential in the accurate quantification of residual calculus.

7. Investigation Purpose and Aims

Some amount of residual calculus has been shown to be biologically acceptable as demonstrated by improvements in clinical parameters despite evidence of incomplete debridement of root surfaces. However, until it is known how much calculus is acceptable or tolerable for optimal healing, total calculus removal is still the goal of periodontal therapy. The difficulty of calculus removal has been outlined. Although both surgical access and fiber optic illumination combined with minimal papillae reflection has somewhat improved the operator's ability to remove calculus, residual deposits remain after therapy.

This study presupposed that, given the improvements noted in calculus removal with open flap access and ordinary dental unit lighting for visibility, further improvement would be gained with the enhanced lighting effect offered by fiber optic illumination of the root surfaces during full flap reflection. Additionally, the study presupposed that the effects would be greater in

multi-rooted teeth than in single-rooted teeth simply due to the anatomical challenges posed by multi-rooted teeth to effective root instrumentation. Also, noting noted past difficulties in quantifying residual calculus and the questionable results in the literature, this study intended to evaluate a potentially more accurate method of both detecting and quantifying residual calculus.

Therefore, the first specific aim of this study was to examine the influence of fiber optic illumination on an operator's ability to mechanically remove calculus from root surfaces during an open flap periodontal surgical procedure. The second specific aim was to relate the effects of fiber optic illumination on calculus removal during such surgeries between both single- and multi-rooted teeth. The third specific aim was to develop and evaluate a new methodology to quantify the residual calculus on root surfaces after mechanical therapy. This methodology would include the use of SEM photographs of debrided root surfaces and the computer-assisted digital analysis of those photographs.

II. Materials and Methods

1. Approach Design

This study included a clinical phase and a laboratory phase. The clinical phase, scaling and root planing under experimental conditions was accomplished in the Department of Periodontics, Wilford Hall USAF Medical Center, Lackland AFB, Texas. The laboratory phase, the examination of teeth for residual calculus and the quantification of the calculus, was conducted at the Clinical Investigation Directorate, Wilford Hall USAF Medical Center, Lackland AFB, Texas and the USAF Research Laboratory, Brooks AFB, Texas. The study was conducted in two parts. The evaluation of single-rooted teeth (Part 1) and multi-rooted teeth (Part 2) was conducted simultaneously.

2. Study Population and Requirements

The population considered as subjects for this study were patients that presented to the Departments of Periodontics and/or Prosthodontics at MacKown Dental Clinic, Wilford Hall USAF Medical Center, Lackland AFB, Texas. Subjects were considered for inclusion if they had been diagnosed with adult periodontitis and required the extraction of hopeless teeth as part

of a comprehensive periodontal and/or prosthodontic treatment plan. Age (a minimum of 18 years) and sex were not used as exclusion factors unless the patient was diagnosed with juvenile periodontitis or other age-specific entities of periodontitis having negligible amounts of subgingival plaque and calculus. A thorough medical history was taken and a comprehensive periodontal examination was given in the development of a comprehensive treatment plan for all patients. Prosthodontic consideration was given in all treatment plans.

Forty-five teeth were required for the study. These teeth exhibited moderate to severe periodontitis ($PD \geq 5$ mm) and were considered hopeless in the overall periodontal and/or prosthodontic plan developed for the patient. These teeth were to be scaled and root planed and then extracted for analysis. Twenty single- and 20 multi-rooted teeth were randomly selected for treatment and examination. In addition, 5 untreated control teeth with similar disease were randomly selected to substantiate the presence and quantity of calculus on study teeth. The removal of all the study teeth was consistent with the standards of care, and teeth were used only if they required extraction regardless of whether or not the patient participated in the study. An informed consent giving a detailed explanation of the goals and parameters of the study was signed by each patient.

3. Selection and Placement Parameters

Patients selected for the study met the following criteria:

1. Diagnosed as having Adult Periodontitis

2. One or more teeth with a pocket depth of ≥ 5 mm; deemed periodontally or prosthodontically hopeless
3. No subgingival scaling or root planing on selected teeth within the last year
4. No medical contraindications to treatment

Teeth included in the study met the following criteria:

1. Either a single-rooted maxillary or mandibular anterior or premolar tooth
or
maxillary or mandibular first or second molar with at least one furcation of
Degree II or III according to the classification system of Glickman
2. A pocket depth of 5 mm or more and a hopeless prognosis
3. No subgingival scaling or root planing within the past year

Control teeth (scaled and root planed under ordinary dental unit lighting) and test teeth (scaled and root planed under fiber optic illumination) were taken from the same patient whenever possible. When this was not possible, priority was given to filling the test group first. Teeth were randomly assigned to the study groups of both parts 1 and 2 on a rotating basis.

Part 1 (single-rooted teeth) of the study consisted of 20 teeth that were placed in two groups. The control group "A" teeth ($n=10$), exposed during an open flap surgery, were scaled and root planed using direct vision and routine dental unit illumination. The test group "B" teeth ($n=10$), after exposure in the same manner, were scaled and root planed using direct vision and fiber

optic illumination (Designs for Vision Dualite Unit®). No magnifying loops or glasses were used.

Part 2 (multi-rooted teeth) of the study also consisted of 20 teeth that were placed into two groups. The control group "C" teeth (n=10), after exposure with an open flap procedure, were scaled and root planed using direct vision and routine dental unit illumination. The test group "D" teeth (n=10), exposed in the same manner, were scaled and root planed using direct vision and fiber optic illumination (Designs for Vision Dualite Unit®). Again, no magnifying loops or glasses were used.

In order to substantiate and quantify the calculus prior to treatment, 5 additional teeth, which met all criteria, were randomly extracted as untreated controls.

4. Tooth Preparation and Evaluation Parameters

Both test and control teeth were evaluated and treated for study using identical parameters. Probing depth was measured using a standard periodontal probe (North Carolina-15). The probe was aligned parallel to the root surface and six measurements, to the nearest millimeter, were taken to include the mesiobuccal, buccal, distobuccal, lingual, distolingual, and mesiolingual tooth surfaces. Interproximally, the probe was positioned as far as possible within the embrasure and angled no more than 5 degrees from the vertical axis of the tooth to end below the contact. Furcations were classified prior to extraction as Degree I, II, or III according to the system of Glickman. Additionally, prior to treatment, six reference points (same positions as probing measurements) were marked with a highspeed handpiece and a $\frac{1}{2}$ round bur at the level of the

free gingival margin if it was located below or above the cementoenamel junction (CEJ). The six reference points were joined, after extraction, by a $\frac{1}{2}$ round bur in a highspeed handpiece in order to form a reference groove at the gingival margin.

5. Documentation

After flap reflection, intraoral clinical photographs of all teeth were taken prior to root treatment. In addition, photographs were taken of all teeth immediately after extraction. All clinical parameters, as previously described, were recorded. The tooth number and the methodology of lighting was recorded after giving each tooth a coded number to ensure anonymity. Although no time limit was given, the time spent scaling and root planing each tooth was recorded (in seconds) and subdivided into times spent with hand, rotary, or ultrasonic instruments for later statistical analysis. After removal, study teeth were individually stored in bottles that were identifiable only by the specific number that identified a particular tooth, again to ensure anonymity during analysis.

6. Treatment Parameters

Prior to treatment, a comprehensive treatment plan was presented to all patients. The appropriate informed consent form was completed and signed.

The operators for the study were all board certified periodontists or graduate periodontal students. Intravenous conscious sedation was rendered as needed within the confines of the medical history. Local anesthetic, 2% xylocaine with 1:100,000 epinephrine and/or .5% bupivacaine with 1:200,000 epinephrine, was administered during all procedures as required, unless the medical history required that a suitable alternative be used.

Prior to flap reflection, reference notches were made to mark the gingival margin with a $\frac{1}{2}$ round bur in a highspeed handpiece. The notches were made at the mid-facial, mid-lingual, and the four line angles of the teeth as previously described. Direct access was then afforded by the reflection of buccal and lingual mucoperiosteal flaps (*Plate 2*). Granulation tissue was gently removed to aid visibility. No operator used telescoping lenses during the procedures, but all patients and operators were required to use appropriate eye protection in compliance with standard precautions.

The root surfaces were scaled and root planed with hand, rotary and/or ultrasonic instruments. A rotary diamond was used, as required, in minimally accessible areas. The operators spent as much time as required to produce the clinical endpoint. The clinical endpoint was reached when the operator, visually and tactiley, determined that all plaque and calculus had been removed from all root surfaces from the gingival margin to the attachment apparatus.

All treated control teeth were scaled and root planed using direct vision and the dental unit lighting. All test teeth were scaled and root planed using direct vision and head-mounted fiber optic illumination (Designs for Vision Dualite Unit®). The five untreated controls were left untreated by any methodology.

Plate 2

Photographs of the surgical exposure of test teeth. *Panel A:* Photograph of the surgical exposure of single-rooted teeth. *Panel B:* Photograph of the surgical exposure of multi-rooted teeth.



A



B

After debridement, the test and control teeth were extracted using extreme caution not to engage or disrupt the root surfaces as much as possible. The surgical flaps were appropriately sutured as required. Both verbal and written post-operative instructions were given to all patients, and escorts were required for all sedated patients. Analgesics, antibiotics, and surgical dressings were delivered or prescribed as indicated. Appropriate follow-up appointments were scheduled.

7. Tooth Management

Following extraction, each tooth was gently brushed and rinsed in cold running water for two minutes to remove any loose debris or blood (*Plate 3*). The reference points were then connected by a groove placed with a $\frac{1}{2}$ round bur in a highspeed handpiece. The tooth was placed in an individual container of sterile water for storage until examination. The bottle was appropriately marked with the number to allow for the blind examination for residual calculus.

8. Analysis of Teeth

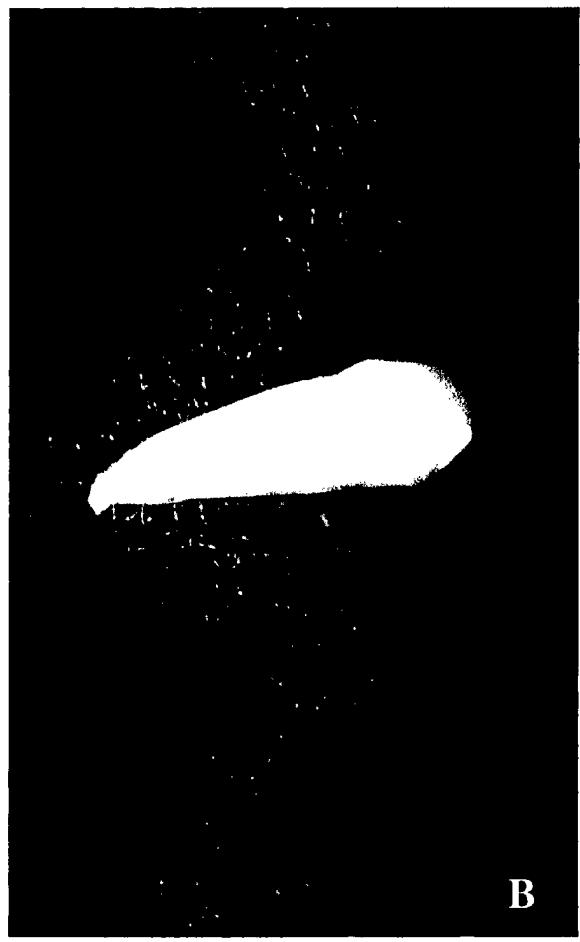
At the start of the laboratory phase examination, the teeth were gently removed from the storage containers and rinsed again in cold running water. Multi-rooted teeth were sectioned with an ultra-thin laboratory disc to allow viewing of the inner aspects of the roots and the furcations ceilings (*Plate 4*). These cuts were made to within approximately 1-2 mm of the

Plate 3

Photographs of debridged teeth. *Panel A*: Photograph of debridged multi-rooted tooth prior to gentle rinsing and brushing to remove loose debris. *Panel B*: Photograph of debridged single-rooted tooth after gentle rinsing and brushing to remove loose debris.



A

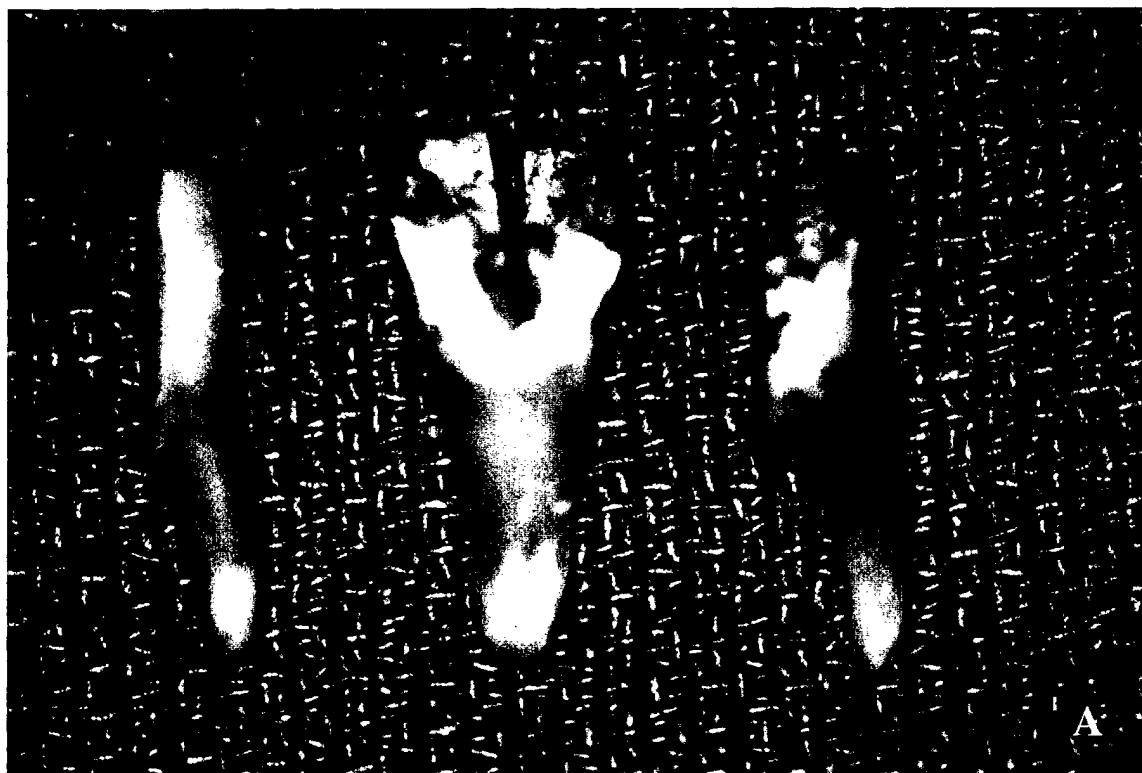


B

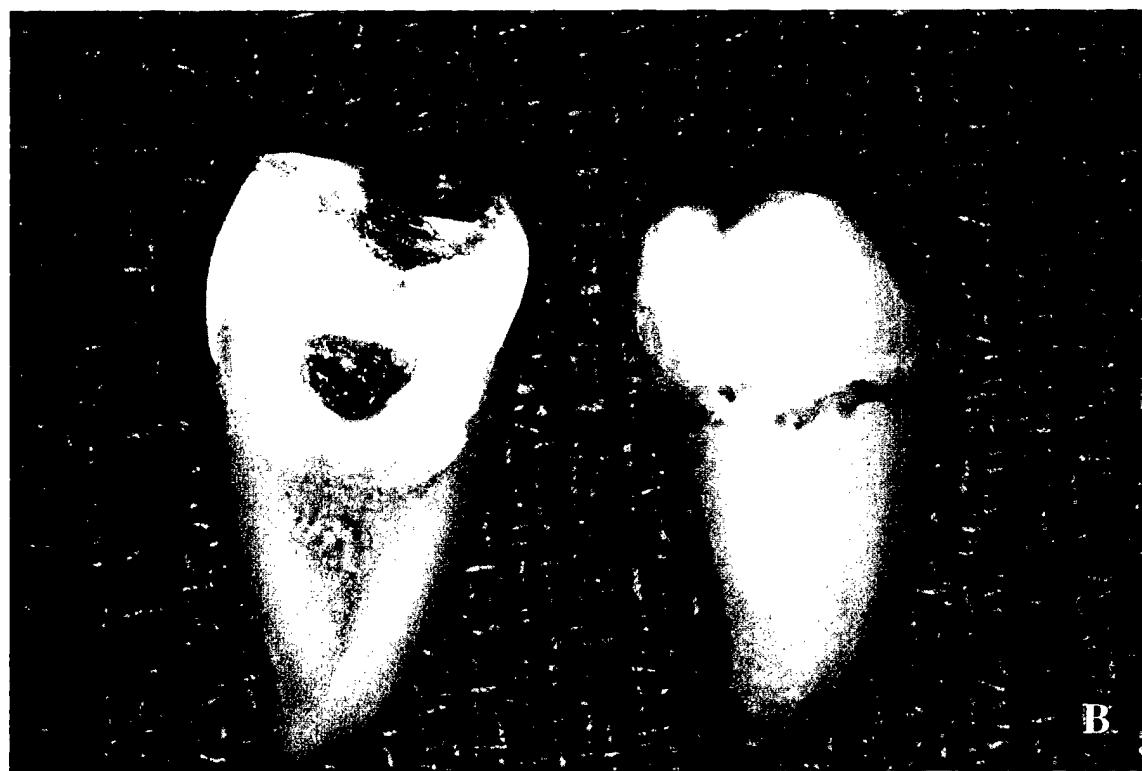
Plate 4

Photographs of sectioned teeth. *Panel A*: Photograph of sectioned maxillary molar.

Panel B: Photograph of sectioned mandibular molar.



A



B

furcation entrance. The root sections were then fractured free with finger pressure only to prevent the disruption of the roots and furcation ceiling by the laboratory disks. All teeth were then taken through a series of graded alcohol solutions and hexamethyldisilizane for desiccation (*Plate 5*). The ethanol solutions were made by mixing 100% ethanol and distilled water in the appropriate concentrations. The hexamethyldisilizane was prepared commercially by Sigma®. The sequence included a 50% ethanol/water solution for 3 minutes (2x), a 75% solution for 3 minutes (2x), a 90% solution for 5 minutes (2x), a 95% solution for 5 minutes (2x), a 100% solution for 10 minutes (2x) and finally, hexamethyldisilizane for 10 minutes (2x).

The desiccated teeth were mounted on SEM platforms with non-conducting tape and then gold-palladium sputter-coated for three minutes at 10 amps and 11 volts with a Technics® sputter-coater (*Plate 6*). Prior to the actual viewing of the teeth by SEM, reference marks were placed longitudinally down the roots with a sharp scalpel (*Plate 7*). This provided orientation during photography and helped prevent duplication.

All debrided surfaces, from the gingival margin to the attachment apparatus, were viewed on an Amray 1200® SEM by a single blinded examiner (*Plate 8*). For standardization, all images were obtained at 30 Kv, a 25 mm working distance, and a magnification of 20x. Although all SEM photographs were taken at a constant working distance and magnification, the magnification was easily increased or decreased to determine if questionable areas were indeed calculus and marked accordingly before returning to the standard settings for all photography (*Plate 9*). A Polaroid #55 black and white film was taken of all areas available for scaling and root planing from the attachment area to the gingival margin reference groove or the CEJ (*Plate 10*).

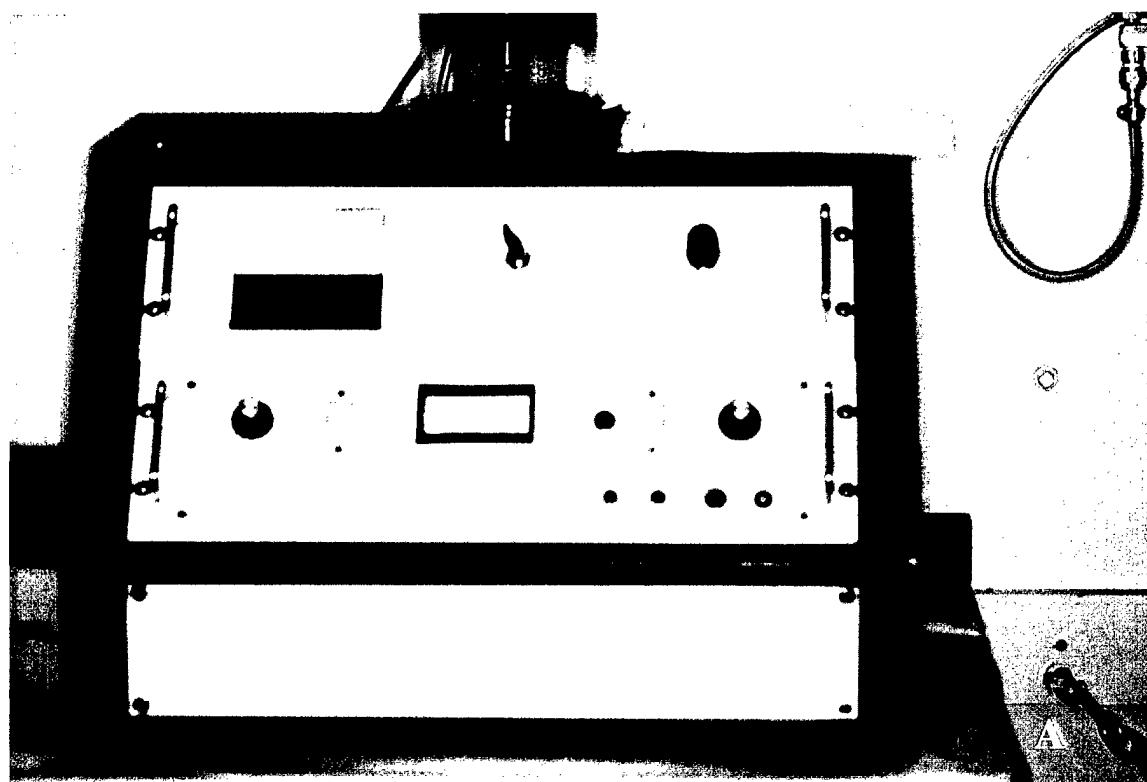
Plate 5

Photographs of desiccated teeth. *Panel A*: Photograph of desiccated multi-rooted teeth. *Panel B*: Photograph of desiccated single-rooted tooth.



Plate 6

Photographs of sputter-coater and gold-palladium covering of tooth. *Panel A*: Technics® sputter-coater. *Panel B*: Photograph of single-rooted tooth ready of SEM analysis.



B

Plate 7

SEM photograph of root surface. Area of interest has been outlined. Reference groove (**RG**) has been marked.

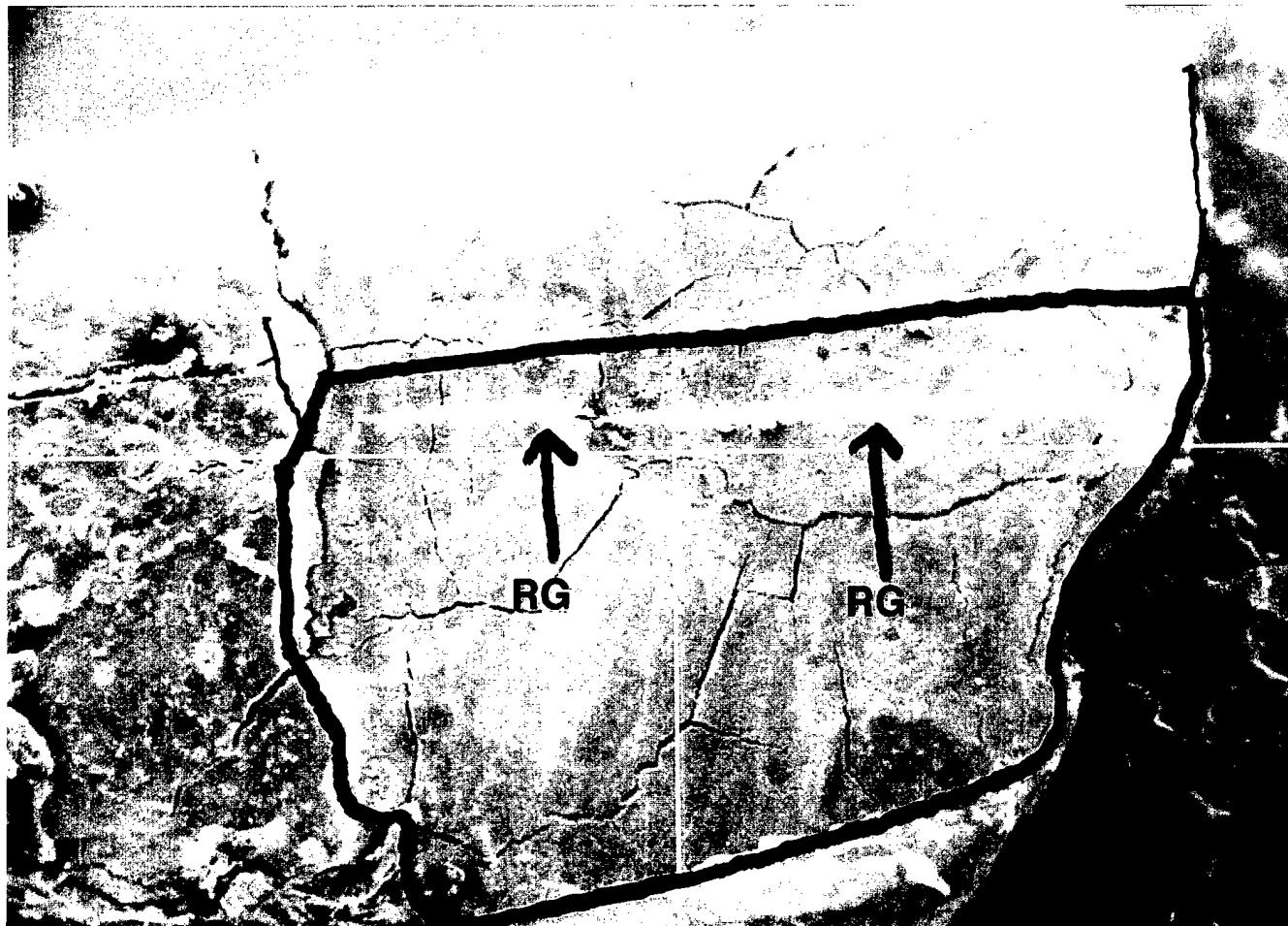


Plate 8

Photographs of AMRAY 1200® scanning electron microscope (SEM). *Panel A*: Instrument panel of SEM. *Panel B*: Vacuum column and specimen chamber of SEM.

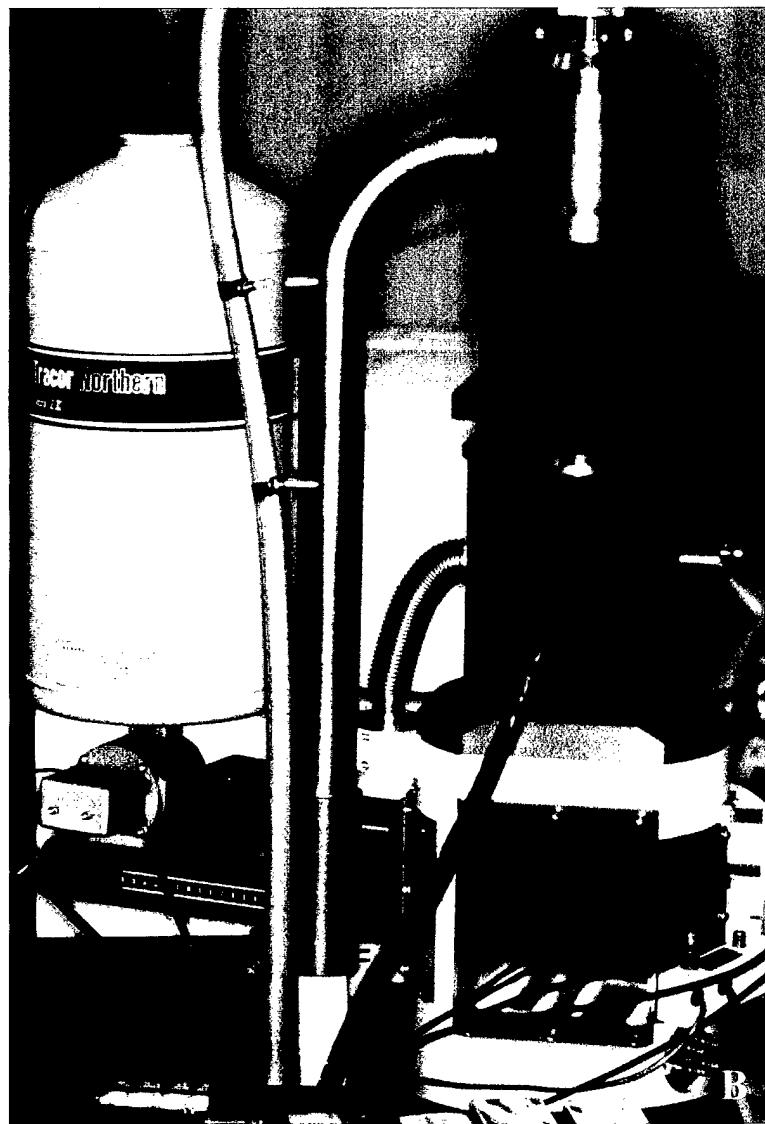
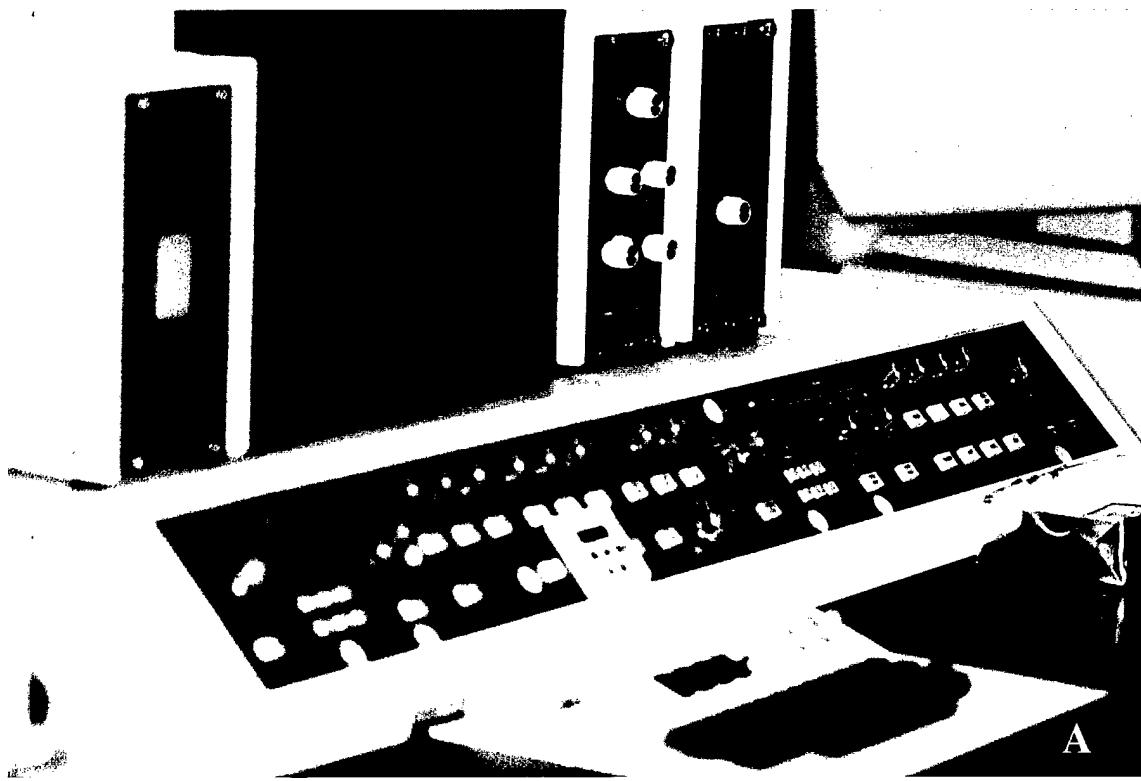


Plate 9

SEM photographs of root surface/calculus at CEJ. *Panel A*: Area of interest at 100x magnification. *Panel B*: Area of interest at 484x magnification.

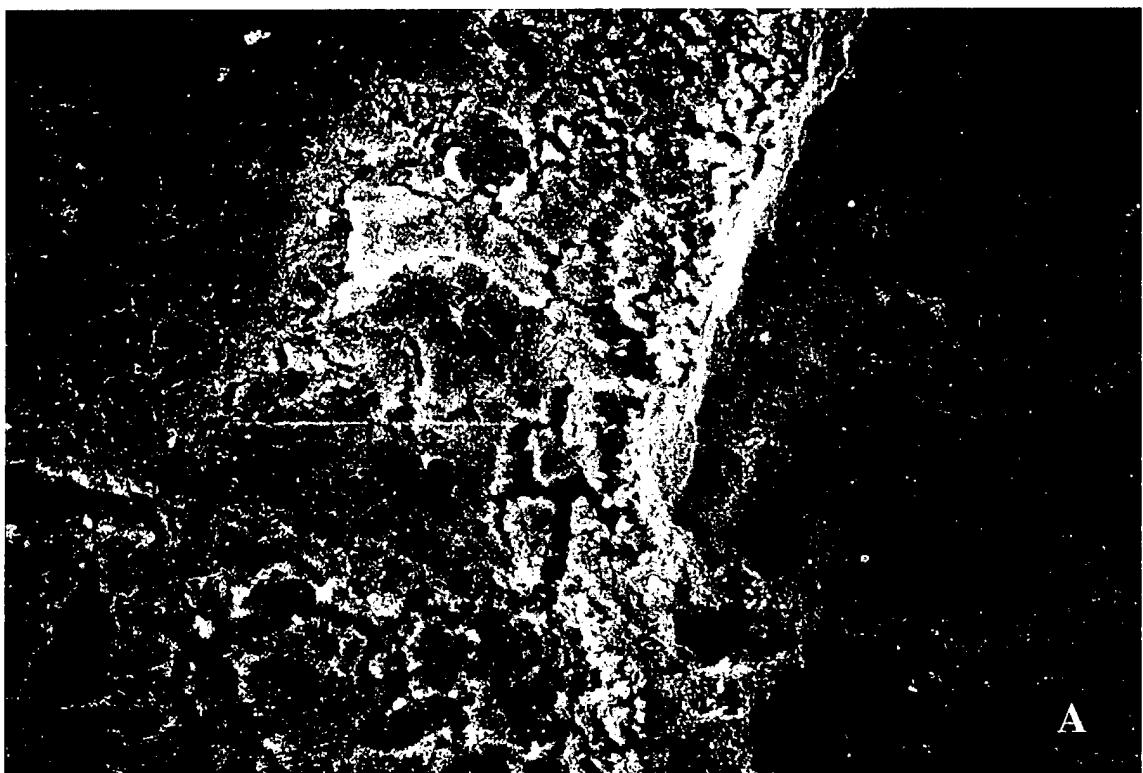


Plate 10

SEM photographs with area of interest outlined. *Panel A*: SEM photograph with area of interest outlined. Reference Groove (G) has been noted. *Panel B*: SEM photograph with area of interest outlined.



B

All final photographs were manually marked by the examiner with black ink to outline total areas available for scaling and root planing and total residual calculus areas on each root surface (*Plate 11*). The examiner was calibrated by a board certified periodontist with an approximate 90% agreement in calculus detection. The outlining ensured that all portions of the root surface were recorded and quantified. Additionally, it ensured that all calculus areas were noted and circumscribed for quantification. The outlined sections were also later subdivided into smaller areas to allow for an easier computer image capture and digital transfer.

All of the sections of the photographic images were subsequently captured by the Olympus Image Analysis System® and converted to a digital image (*Plate 12*). Using the Image Pro Plus Program® (*Plate 13*) with both a manual and automated cursor, the total areas of root surface and residual calculus for all debrided surfaces on each tooth were then quantified into pixel units (*Plate 14*). These standard pixel units were then subjected to statistical analysis.

9. Statistical Management of Data

The statistical analysis of interactions within the data was completed in several ways. In order to rule out the biases of time spent instrumenting and pocket depth, a 2-way ANOVA was completed for both the treated control and test teeth. A 1-way ANOVA compared the percentages of calculus on untreated control teeth versus the treated teeth, with either type of lighting methodology, and compared these in both single- and multi-rooted teeth.

Plate 11

SEM photographs with area of interest outlined. *Panel A*: SEM photograph with area of interest outlined. *Panel B*: SEM photograph with area of interest outlined. Calculus (C) has been indicated.

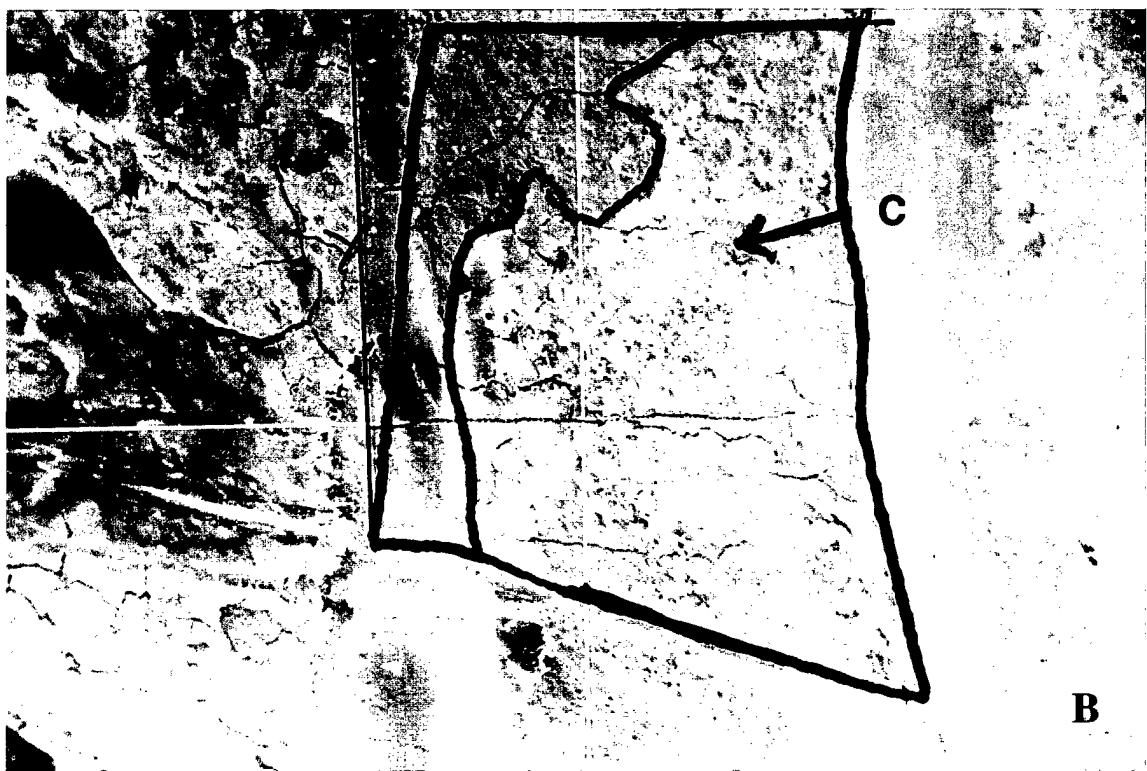
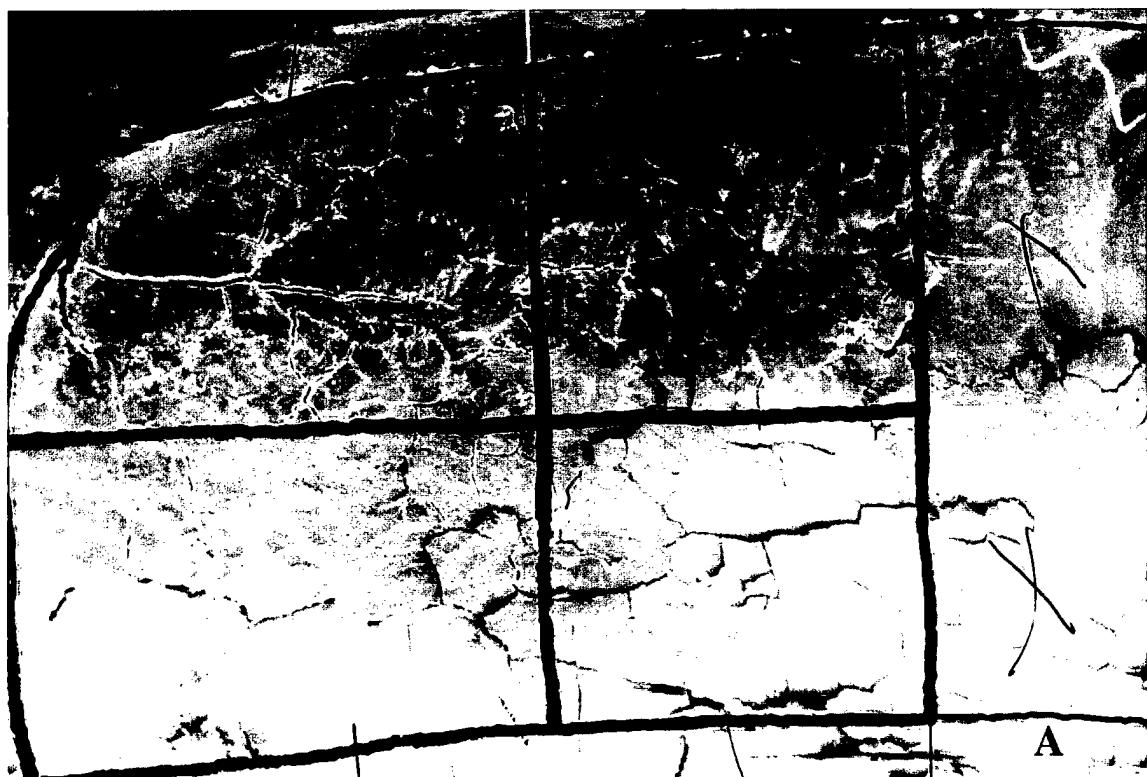


Plate 12

Photographs of Olympus Image Analysis System®. *Panel A*: Photograph of video camera interface of Olympus Image Analysis System®. *Panel B*: Photograph of computer interface of Olympus Image Analysis System® with Image Pro Plus® software.

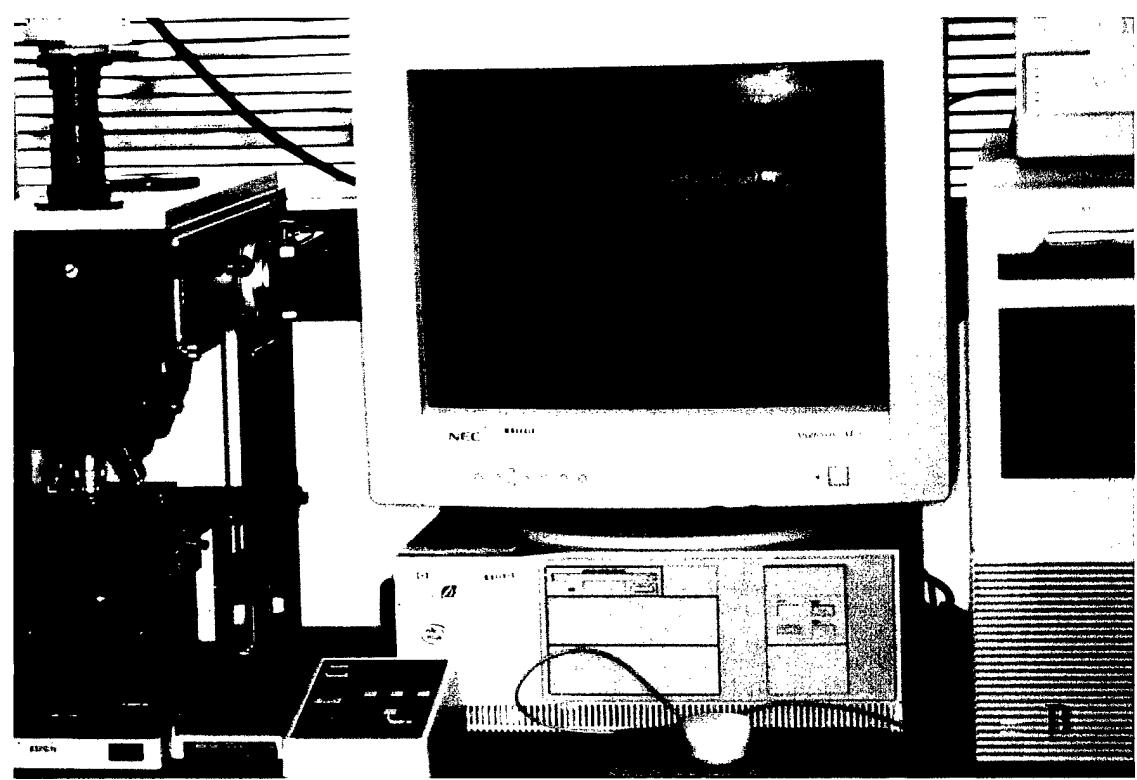
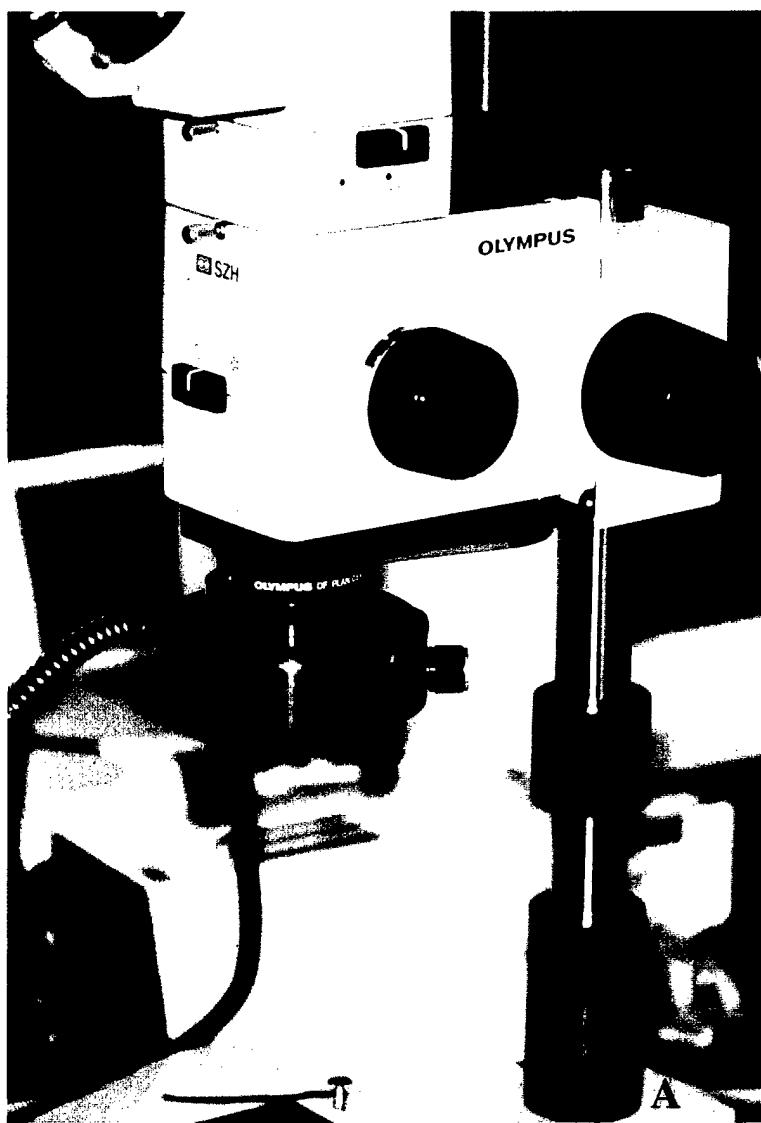
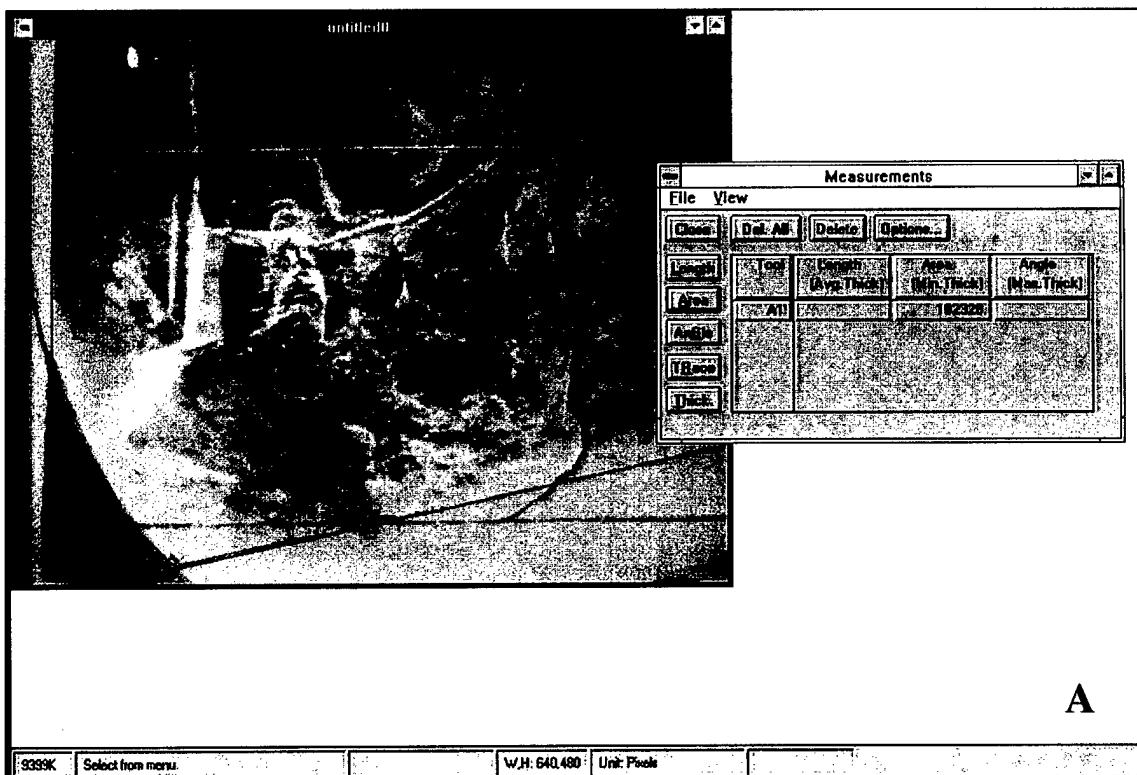
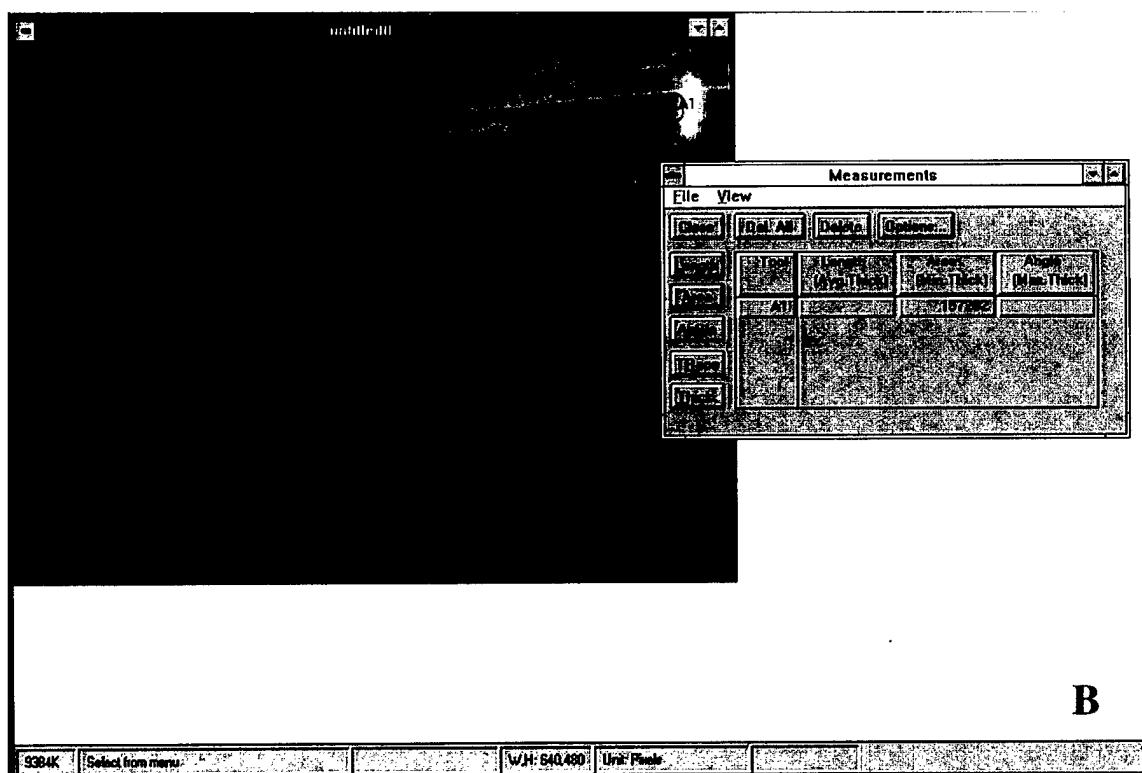


Plate 13

Photographs of outlined area of interest as shown with Image Pro Plus® software. *Panel A*: Outlined area of interest with area in pixel units. *Panel B*: Outlined area of interest with area in pixel units.



A

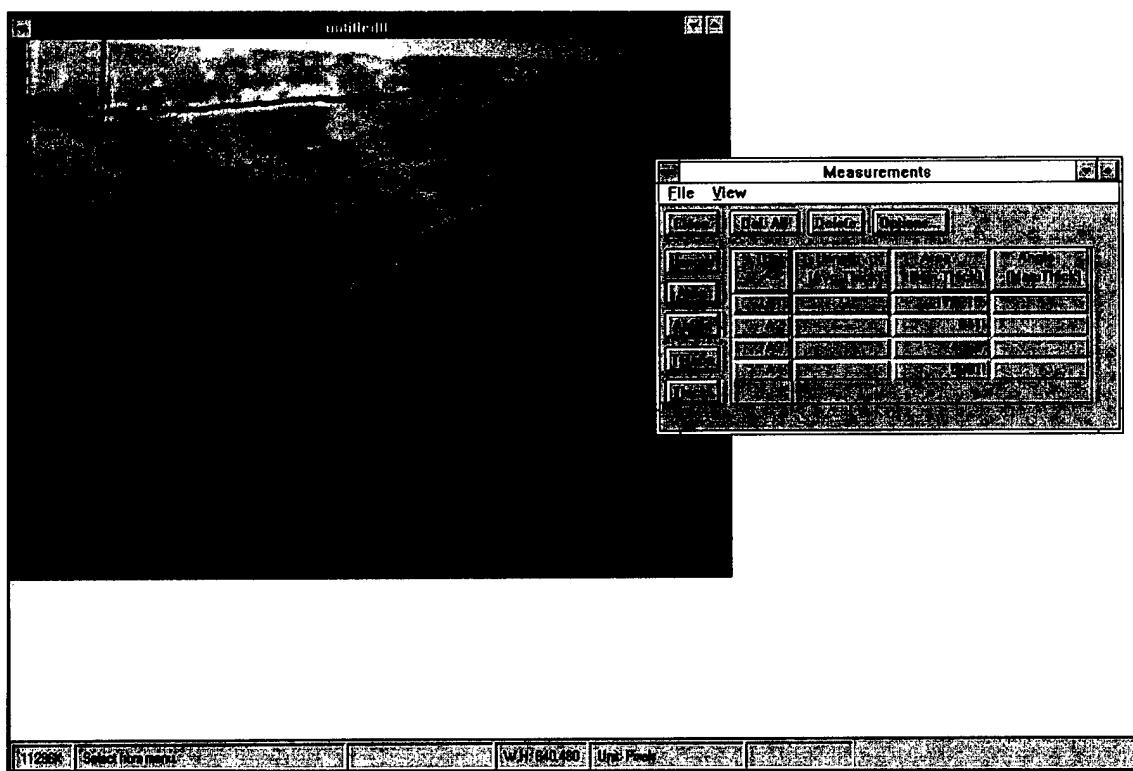
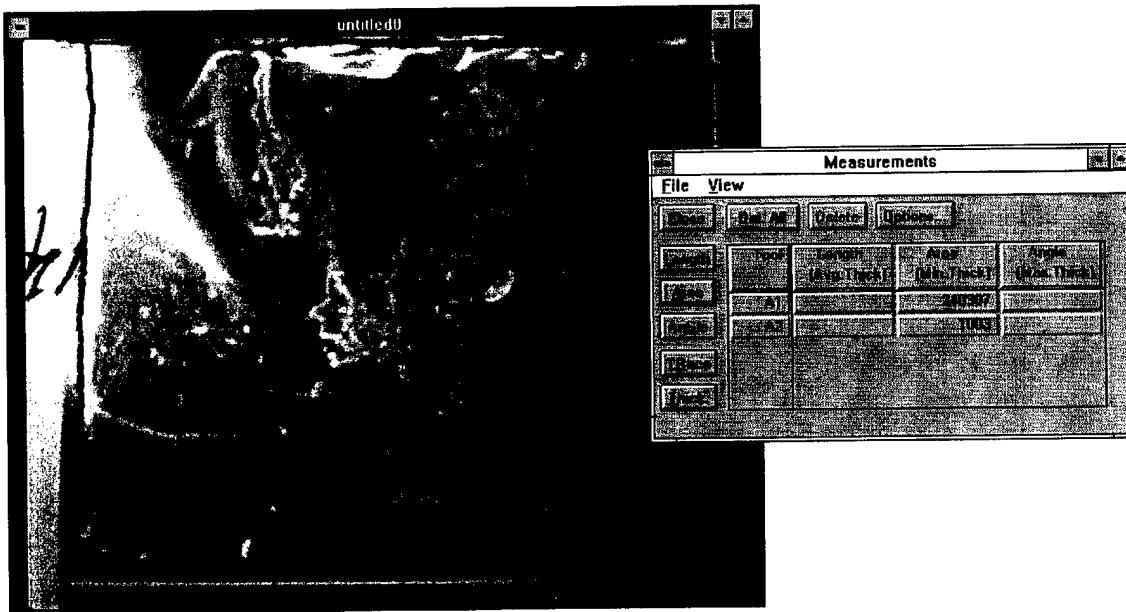


B

Plate 14

Photographs of outlined area of interest and calculus as shown with Image Pro Plus® software.

Panel A: Outlined area of interest and calculus in pixel units. *Panel B:* Outlined area of interest and calculus in pixel units.



III. RESULTS

1. Calculus Detection and Quantification-Specific Aim #3

A total of 606 SEM photographs were taken to record all debridable surfaces of the 45 teeth. These SEMs revealed that there was indeed calculus on all of the untreated control teeth, and that there was significantly more on untreated teeth than on the treated teeth (Figure 1). Additionally, residual calculus, to various degrees, was detected on the majority of the root surfaces of the treated teeth. The calculus, by varying the working parameters of the SEM, was easily detectable along the root surfaces, and the final SEM photographs clearly represented these areas and allowed for their differentiation from clean surfaces. As in other studies, the residual calculus was primarily found at the CEJ, furcation areas, line angles and in deep grooves along the root surfaces.

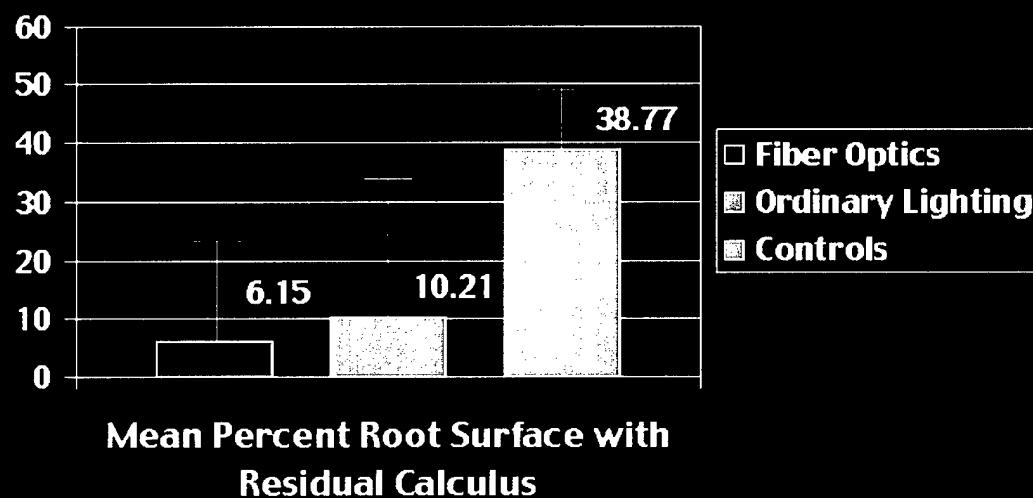
A total of 2,176 computer images were generated from the SEM photographs. These computer images were also clear and easily allowed the outlining of surface areas and calculus areas to produce quantifiable data. The standardized pixel units of area resulted in objective data for study.

Figure 1

Mean percent root surface with residual calculus on both control teeth (no treatment)

and teeth treated under fiber optic illumination or ordinary dental unit lighting.

Mean Percent Residual Calculus



2. Light versus No Light-Specific Aim #1

Aim #1 results pertain to the first experimental objective which was to examine the effect of fiber optic illumination versus ordinary dental unit lighting on an operator's ability to remove calculus from roots surfaces during an open flap procedure.

Residual calculus was detected on a mean of 8.18% of the all the root surface area available for debridement. Using ordinary dental unit lighting, the mean cleanable root surface area covered by root calculus was 10.21%. With fiber optic illumination, this mean was 6.16%. For the untreated controls, the mean root surface covered with calculus was 38.77% (*Figure 2*). Using a 1-way ANOVA, the use of fiber optic illumination allowed the operator to remove more calculus from the root surfaces than that using ordinary dental unit lighting, and the difference was significant ($p = .044$).

3. Results in Single- Versus Multi-Rooted Teeth-Specific Aim #2

Aim #2 results pertain to the second experimental objective which was to examine the results of using fiber optic illumination versus ordinary dental unit lighting and relate these results in single- versus multi-rooted teeth.

Using ordinary dental unit lighting, the mean debridable root surface area with residual calculus was 9.22% for single-rooted and 11.22% for multi-rooted teeth (*Figure 3*). With fiber optic illumination, the mean were 5.73% for single-rooted teeth versus 6.58% for multi-rooted teeth. Although fiber optic illumination improved calculus removal by 42% in single-rooted and 38% in multi-rooted teeth, the difference was not statistically significant ($p = .766$).

Figure 2

Fiber optic illumination versus ordinary dental unit lighting. Numbers indicate mean percent root surface with residual calculus. * (p=.044).

Fiber Optic Illumination Versus Ordinary Dental Unit Lighting

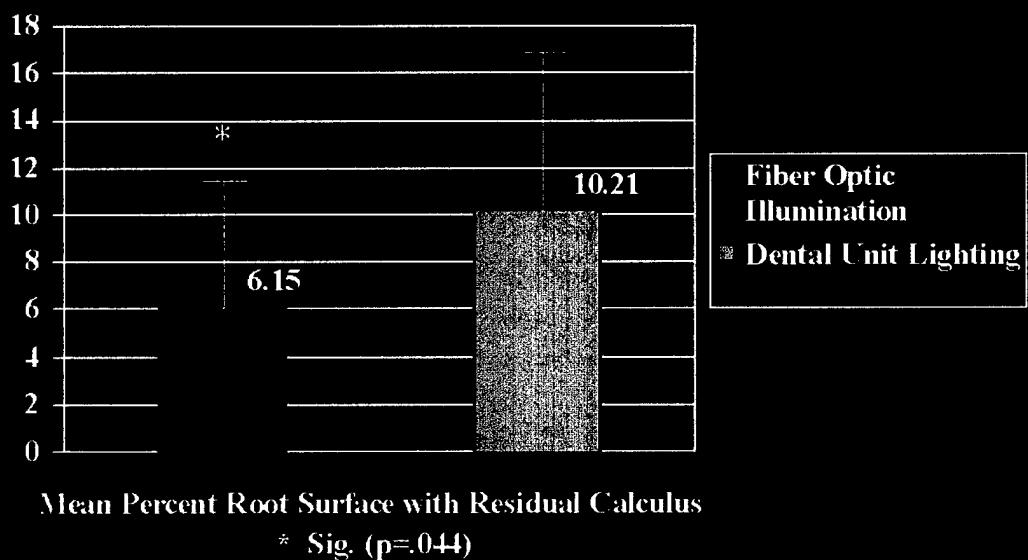
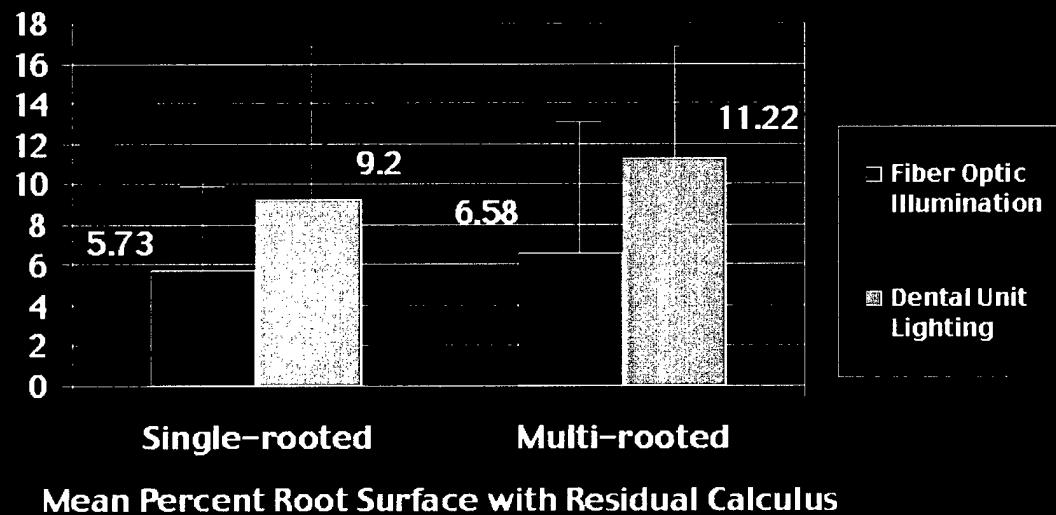


Figure 3

Effects of lighting on single- and multi-rooted teeth. Mean percents of root surface with residual calculus value have been displayed for both fiber optic illumination and ordinary dental unit lighting in both single- and multi-rooted teeth.

Effects of Lighting on Single- and Multi-rooted Teeth



4. Additional Data-Results Versus Pocket Depth

With the additional data collected, further analysis was conducted. This data was included in order to rule out any biases that may have negated the effects of lighting alone on the results. Using ANOVA and considering the average pocket depth, the use of ordinary light versus fiber optic illumination did not produce a significant difference in the mean percent of residual calculus ($p = .364$, *Figure 4*). In a similar analysis, the average pocket depth did not produce a significant difference in calculus removal in single- versus multi-rooted teeth.

5. Additional Data-Results Versus Type of Instrumentation

In considering the time used with hand instruments, the lighting method chosen did not significantly change the amount of time spent ($p = .420$, *Figure 5*). However, using either method of lighting, significantly more time was used with hand instruments on multi- versus single-rooted teeth ($p = .006$, *Figure 5*). The same results held true when considering the time used with ultrasonic instruments. There was not a significant difference when choosing either light source ($p = .078$, *Figure 6*), but a significant difference was noted when debriding multi- versus single-rooted teeth ($p = .000$, *Figure 6*) with ultrasonic instruments. As expected from above, significantly more time was used to debride multi- versus single-rooted ($p = .000$, *Figure 8*) regardless of the lighting and regardless of the type of instrumentation.

Figure 4

Effects of mean average pocket depth. Mean pocket depth in millimeters is indicated for both fiber optic illumination and ordinary dental unit lighting in both single- and multi-rooted teeth.

The Effects of Mean Average Pocket Depth

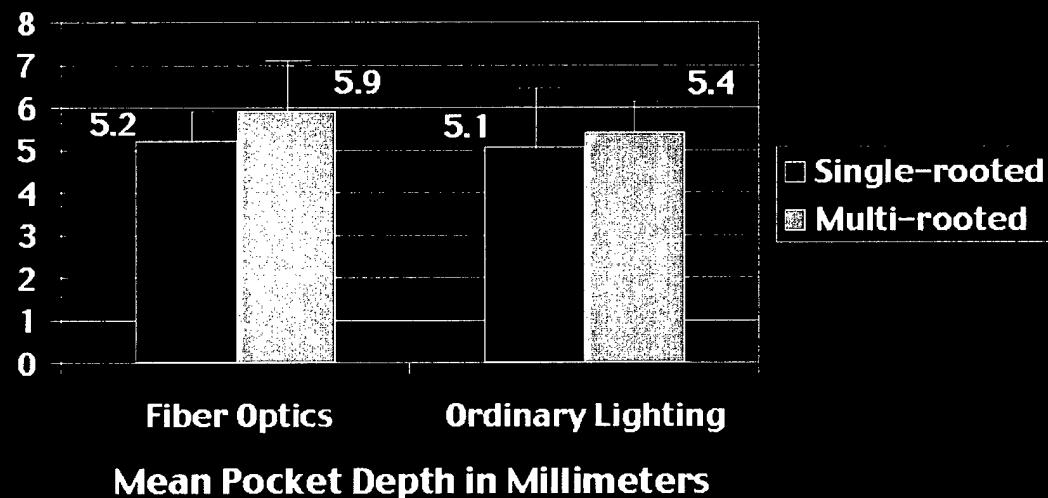


Figure 5

Effects of mean time with hand tools. Mean time in seconds is indicated for both fiber optic illumination and ordinary dental unit lighting in both single- and multi-rooted teeth.

Effects of Mean Time With Hand Tools

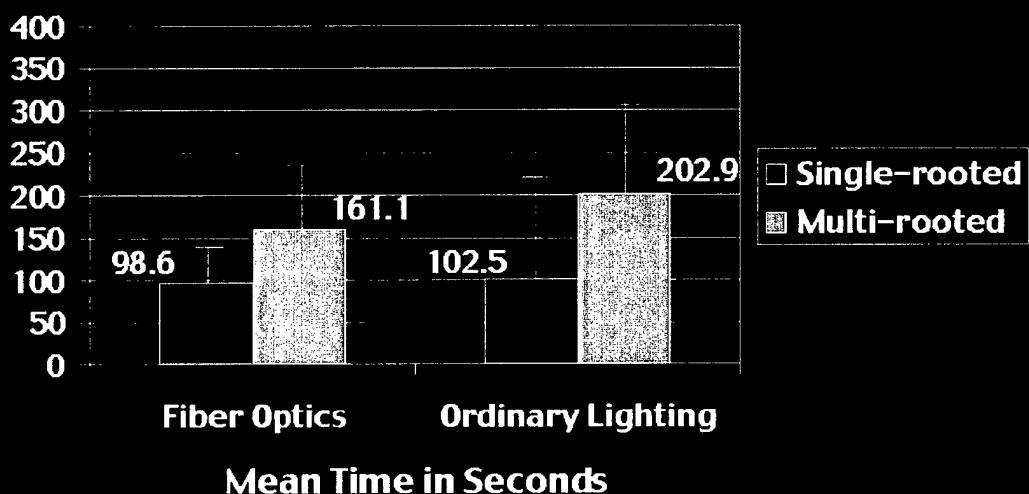


Figure 6

Effects of mean time with ultrasonics. Mean time in seconds is indicated for both fiber optic illumination and ordinary dental unit lighting in both single- and multi-rooted teeth.

Effects of Mean Time With Ultrasonics

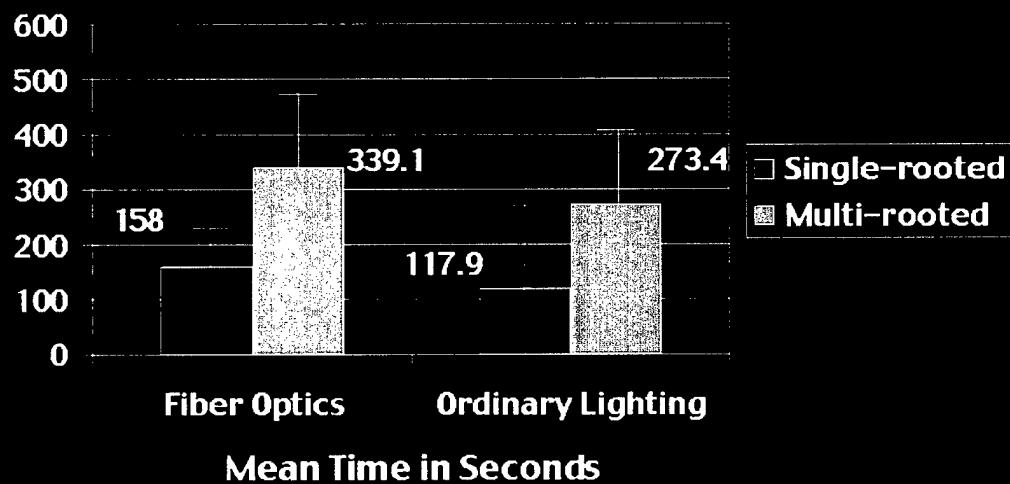
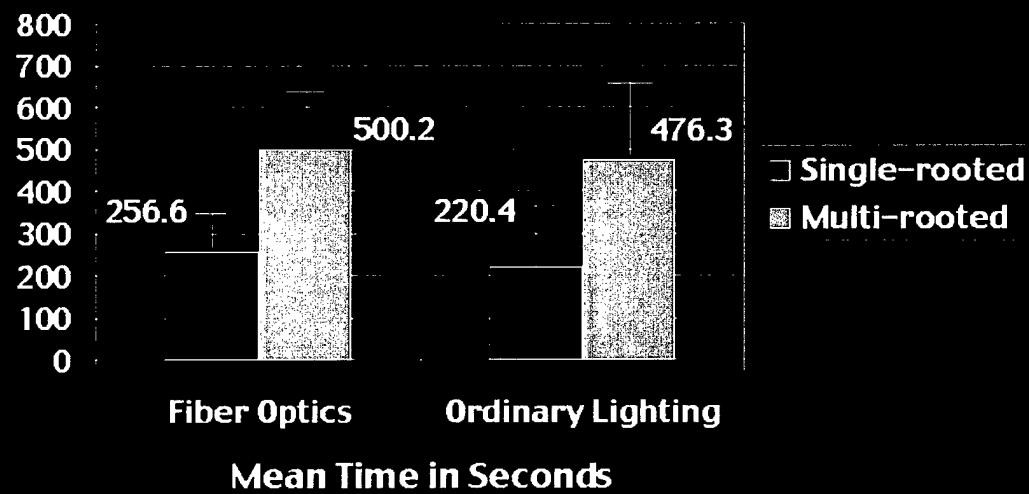


Figure 7

Effects of mean total time instrumenting. Mean time in seconds is indicated for both fiber optic illumination and ordinary dental unit lighting in both single- and multi-rooted teeth.

Effects of Mean Total Time Instrumenting



IV. DISCUSSION AND SUMMARY

1. Improvement With Fiber Optics

Prior to starting, this study reviewed the positive improvements that resulted with open flap debridement and made the assumption that the improvements were the result, primarily, of improved visibility. It therefore postulated that if visibility could be further enhanced, operators could get closer to the “gold standard” of total calculus removal. Only limited studies have approached this idea (Reinhardt *et al.*, 1985, 1991 and Johnson *et al.*, 1989). These studies showed that fiber optic illumination enhanced calculus removal. In these studies, however, illumination was provided with the fiber optic illumination of a handpiece, and only minimal papilla reflection was employed. In the current study, fiber optic illumination was employed using a high intensity, head-mounted fiber optic illumination unit. Additionally, open flap debridement was used to provide total access to the root surfaces.

This study confirmed previous observations that residual calculus remained even after open flap debridement (Caffesse *et al.*, 1985). Previous studies (Buchanan *et al.*, 1986) indicated that improved access and visualization might improve efforts to remove calculus, and indeed the results confirmed this. However, it was evident that calculus still remained. The data revealed that significantly less residual amounts of calculus were left when fiber optic illumination was employed. The pocket depths around the teeth and the time required to debride the surfaces were recorded during instrumentation. These were recorded to test their influence on the primary

focus of the study which was to test the efficacy of fiber optic illumination on calculus removal during open flap debridement. The data indicated that these parameters of instrumentation did not significantly effect the results.

Also, the residual calculus was most frequently identified in areas suggested in other studies (Brayer *et al.*, 1989). These areas were the CEJ, line angles, furcations and deep residual grooves and depressions. Fiber optic illumination significantly increased the operators ability to remove calculus by improving visibility, but areas that remained difficult to visualize (i.e. furcations) continued to harbor some residual calculus.

2. Single- Versus Multi-Rooted Teeth

Interestingly, this study indicated that the improved results with fiber optic illumination were equally shared among both single- and multi-rooted teeth. It would seem that multi-rooted teeth, with narrow furcations and hidden ceilings, might provide niches for calculus that would be better visualized and therefore removable with proper illumination. Although the data suggested that this was indeed so, the results indicated that the differences were not significant. These results were unexpected, but they may have been related to further anatomical considerations or in the general differences in surface areas between the two types of teeth.

3. Additional Analysis

Additional data was collected and analyzed. The probing pocket depth was recorded at six points on each tooth and averaged. The results indicated that average depth did not produce significant differences in the residual calculus on either single- or multi-rooted teeth. In considering this, it could be assumed that regardless of the depth, the open flap provided access to all portions of the multi-rooted tooth to be debrided. It can be concluded that improvements must be related to improvements in visibility and not access.

Also, regardless of whether fiber optic illumination or ordinary dental illumination was used, average pocket depth did not create a significant difference in the operators ability to remove calculus. These results are similar to a previous study (Parashis *et al.*, 1993). The effect of the depth of the pockets appeared to be essentially removed in an open flap procedure and anatomy and access seemed to take over as factors opposing total removal of all calculus.

The time spent with hand instruments, ultrasonic instruments, and total time was also recorded. No operator chose to use rotary instruments. The individual times spent with either type of instrumentation or the combination of the two types were not significantly different with either fiber optics or ordinary dental unit illumination. This would essentially negate the possibility that simply more time was being spent with the improved lighting. It can be seen from the data that although the mean time spent with fiberoptics was greater than ordinary unit lighting, the standard deviation revealed a wide variety in individual times spent. Indeed, the individual data bears this out. The minimum combined instrumentation with fiber-optic illumination was 135 seconds and the maximum was 730 seconds. The minimum combined

instrumentation time with ordinary unit lighting was 101 seconds and the maximum was 720 seconds.

However, using either type of instrument, or the combination of instrumentation, more time was employed in the debriding the multi-rooted versus single-rooted teeth. These results were expected. Multi-rooted teeth with the additional number of roots and furcations made debridement more difficult. Thus, it would be expected that such teeth would require more time using any type of instrumentation. The data indicated that either lighting method did not make a significant difference in the time of instrumentation. With the endpoint of the visual and tactile absence of calculus, it appeared that the improvement in visualization afforded with fiber optic illumination did not make a significant difference in the time spent instrumenting.

4. Methodology of Quantification

This study attempted to improve the quantification of residual calculus after instrumentation. The original intent of this study was to employ a Methylene Blue solution to stain the residual calculus. However, a previous study indicated that such an approach stained other debris in addition to calculus (Breninger *et al.*, 1974). It was determined that only residual calculus would be recorded in this study. Also, some prior studies used a stereomicroscope and grid system to quantify calculus. Such an analysis, which counts calculus as occupying the grid regardless of the amount of space occupied, overestimates the amount of residual calculus (Eschler *et al.*, 1991).

This study used a two-tiered system to quantify the area of residual calculus on the surface of the roots. The first tier was the use of SEM photographs for calculus detection on root surfaces. Initial results on experimental teeth revealed that a SEM could be used to accurately distinguish calculus on root surfaces. It was also learned that when any area of concern was viewed, the magnification could be increased or decreased to confirm the presence or absence of calculus. Two concerns with using SEM photographs emerged. First, in using the SEM to produce photographs to be later quantified, a standardization was needed. It was determined that all final photographs would be at a constant kV, working distance and magnification. Second, in dealing with such high magnifications, orientation was initially a concern. To solve this problem, scalpel cuts were made at line angles and at mid-roots for orientation along the root surfaces.

Essentially two potential problems could be associated with the use of SEM photographs in this study. The first problem could be the determination of what was indeed calculus at such a magnification. This problem was addressed in two ways. First, with multiple pre-study experimental teeth with obvious visual calculus, calculus visualization on SEMs was confirmed and its photographic expression was determined. Secondly, reliability of calculus confirmation on SEMs was confirmed by a second examiner. This board-certified periodontist confirmed a 90% reliability in calculus detection on SEM photographs.

The second problem was inherent in the use of a 2-dimensional SEM photograph to capture the surface area of a conical root. Although not removed, this effect was minimized by using a constant working distance and magnification and in keeping the areas of concern as small possible as evidenced by the over 600 total SEMs for the 45 teeth.

The second tier was the use of digital images for computer analysis and quantification of calculus. The SEM photographs were easily transferred to digital images. A single SEM

photograph required multiple images as indicated in the over 2,100 computer images. The systems images were standardized at 90% to produce equal images. A computer-assisted or manually-employed cursor allowed the outlining of the perimeters of the root surface areas and the calculus areas under investigation. The program would automatically convert the areas in total pixel units and thereby reduced human error.

There were two possible problems associated in converting the SEM photographs to digital images. The first one is that pixel units are square. However, at the magnification employed and millions of pixels counted, the effects were minimized because all roots were effected equally with either type of lighting. Secondly, at higher magnification, it was apparent that the margins of the calculus were not abrupt but sloping. Therefore, different results might be expected at varying magnifications. However, again by standardization of the technique and magnification, this effect was minimized and shared equally among all groups for analysis.

5. Future Studies

Future studies might concentrate on further methodologies to improve visibility. One such study might include magnification alone. With an apparent improvement with fiber optic illumination on visibility and the resultant improvement in calculus removal, magnification would seem to provide yet another way to improve visibility. Also, the combination of fiber optic illumination plus magnification might provide the best results of all.

6. Summary

In conclusion, the use of fiber optic illumination during open flap surgery allowed for significantly more calculus to be removed from root surfaces than ordinary dental unit lighting. This was evidenced by a more accurate way to visualize and quantify residual calculus with the use of SEM photographs and the computer-assisted analysis of such photographs. Although the differences in mean percents of residual calculus were not high, the differences in the percentages of improvement were indeed large and shared equally between single- and multi-rooted teeth. Until it's understood how much calculus might be biologically acceptable, total calculus removal should still be the goal of periodontal therapy. The adjunct to therapy of fiber optic illumination is one tool that might be used to closer approach the goal of total calculus removal.

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VITA

Steven L. Bartel was born on July 29, 1956 to Virgil Louis and Dorothy Marie Bartel in Washington, Missouri. Following graduation from Owensville High School in Owensville, Missouri, he attended Southwest Missouri State University in Springfield, Missouri where he earned his Bachelor of Science degree in 1979. Dr. Bartel received his Doctor of Dental Surgery degree from the University of Missouri-Kansas City in 1985. During dental school, Dr. Bartel initiated and completed an additional Master of Public Administration in Health Services Degree from the same university in 1985. Following his dental training, Dr. Bartel completed a general practice residency at the Veterans Administration Medical Center, Leavenworth, Kansas in 1986. After two years of private practice, Dr. Bartel was commissioned as a captain in the United States Air Force in 1990 and has since been promoted to the rank of major. After tours at Lowry AFB, Colorado and Lajes Airfield, Azores, Portugal, he began periodontal residency training at Wilford Hall Medical Center at Lackland Air Force Base in San Antonio, Texas. He anticipates a graduation date of June 1999. Dr. Bartel has been married to his wife Joanne for 11 years and together they have a son Andrew, 9 and a daughter Alyssa, 1. Upon completion of his training, Dr. Bartel anticipates continuing his career with the United States Air Force.